IDA

INSTITUTE FOR DEFENSE ANALYSES

Distributed Simulation-Based C^2 Experiments

D. F. DeRiggi, Project Leader

September 1998

Approved for public release;
distribution unlimited.

IDA Document D-2194

Log : H 98-002411

This work was conducted under IDA's independent research program, CRP 9001-151. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

INSTITUTE FOR DEFENSE ANALYSES

IDA Document D-2194

Distributed Simulation-Based C^2 Experiments

D. F. DeRiggi, Project Leader
R. W. Carpenter
W. W. Lin
T. M. Stone
V. K. Wong

PREFACE

This document was prepared under Central Research Project (CRP) 001-151. It summarizes the results of a command and control experiment conducted in the IDA Simulation Center during June and July 1998. The authors would like to thank Col. John M. Bryden (USA, Ret.), Col. Clifford J. Landry (USA, Ret.), and Dr. Robert F. Richbourg for their contributions as "Over-Commanders" during the course of the experiment. The authors would also like to thank Mr. Kevin Battle, a summer intern, who substituted for a player who became ill, and the reviewers, Dr. Samuel L. Park, Dr. Robert J. Bontz, and Mr. James N. Bexfield for their careful reading and helpful comments. Finally, we wish to express our genuine gratitude to Mrs. Tina M. Higgins and Ms. Natalie R. Kennedy for their very valuable help in conducting the experiment and their assistance in preparing this document.

(This page is intentionally blank.)

TABLE OF CONTENTS

(This page is intentionally blank.)

EXECUTIVE SUMMARY

The purpose of this CRP is twofold: (1) to explore the feasibility of distributed simulation as a medium for conducting C^2 and situational awareness experiments and (2) to investigate the utility of the IDA Simulation Center (SIMCTR) as a venue for such experiments. To accomplish this, a simulation-based experiment consisting of 24 individual trials was conducted in the SIMCTR in which two distinct C^2 structures and two levels of situational awareness were imposed on the participants. Measures of effectiveness were computed for each trial and inferences were made regarding the C^2 structures and situational awareness based on these measures.

The individual trials consisted of simulated company-level armor engagements. Two teams, Red and Blue, contended with one another in each trial. Each team was made up of two operators who controlled entities from a Silicon Graphics workstation (SGI). The operators on a given team acted cooperatively, had access to one another's workstations, and were in a remote location with respect to their opponents.

The underlying simulation used to generate and control combat entities was Modular Semi-Automated Forces (ModSAF) version 2.0. Each side possessed 14 M1A2 tanks, one Stinger-equipped M2 infantry fighting vehicle, and one OH-58 observation helicopter. All engagements took place on a symmetric terrain database modeled on a portion of the Hunter-Liggett Military Reservation. The objective of each engagement was to find and destroy the opposing team's M2.

Two C^2 structures were imposed. The first, sometimes referred to as the "high level of command" consisted of a third team member (the "over-commander") who exercised tactical authority over his team's two ModSAF operators. This over-commander had access to a third workstation at a location remote from both his and the opponents' teams. He communicated his orders to his operators by telephone. The second C^2 structure, called the "low level of command," consisted simply of the two operators acting in concert and on their own authority.

Two levels of situational awareness were imposed also. The first, called the "high level of visibility," was the ability to see all battlefield entities at all times during the trial. This was invoked by accessing a certain window-button sequence in the ModSAF graphical user interface (GUI). The second level of situational awareness, called the "low level of visibility," was the ability to see only the entities belonging to one's own team—plus enemy elements detected by one's own force.

Red always operated under the low levels of C^2 and situational awareness (that is Red never had an over-commander and Red's operators never could see all elements on the battlefield). In each of the individual trials, Blue operated under one of the C^2 conditions (command levels) and one of the situational awareness conditions (visibility levels). Thus four combinations of test conditions were possible. Six replications of each trial combination were conducted. The experiment was a classical 2^2 factorial design.

At the end of each trial, the armor exchange ratio was computed and the winner of the engagement, the team whose M2 survived, was recorded. At the end of the experiment, an analysis of variance (ANOVA) was performed to determine significant factors and interactions with respect to exchange ratios, and logistic regression was applied to determine significant factors and interactions with respect to winning and losing.

The ANOVA indicated that the presence of an over-commander had a significant and detrimental effect for Blue with respect to exchange ratios (in technical terms, C^2 structure was significant below the 10 percent level). On the other hand, there was little evidence of any effect due to situational awareness or the interaction (synergy) between the principal factors. Similarly, with respect to winning and losing, C^2 structure was the only significant factor (again, at the 10 percent level). Without the over-commander, Blue's chances of winning were on the order of four times higher than with the higher authority.

Reasons for the detrimental impact of the over-commander probably lie in the workstation operator's greater capacity to make rapid decisions (about a small unit) and act on them nearly instantaneously than a remotely located commander who is exercising authority for an entire side. Delays due to interpretation of a commander's orders, the clarity of those orders, and the time required to solicit orders all played a part when Blue operated under the more

complex C^2 structure. Another factor may have been the fact that, although the over-commanders all had military experience, the operators were generally more familiar with the peculiarities and foibles of ModSAF. When exercising their own authority, the operators may have been better able to take these factors into account.

The reason situational awareness proved not to be a significant factor may be traced to an artifact of ModSAF that appeared to allow the OH-58 (and other vehicles) to detect opponents after the helicopter was destroyed. Typical (Red) tactics entailed flying OH-58 into enemy territory early in the game. Although the helicopter was vulnerable to enemy fire, and was frequently destroyed after a few "passes," the locations of some Blue elements would often remain on the Red GUI after the helicopter was shot down. As this phenomenon was repeated with other vehicles as well, it was not unusual for a team without "high" visibility or complete situational awareness to ultimately build up a nearly complete image of its opponent.

Regarding the principal objectives of the CRP, the results are somewhat mixed. The SIMCTR facilities were conducive to this type of testing and experimentation. Personnel were extremely helpful and cooperative. A temporary "C^2 cell" was created that allowed the experiment to take place under conditions desired by those participating in the test. Command and control aspects of the test were simplistic but were easily implemented and may be amenable to greater complexity. The situational awareness implementation was unsatisfactory, however. The vagaries of the simulation appeared to dilute the potential impact of this factor and reduced the overall realism of the simulation.

(This page is intentionally blank.)

BACKGROUND AND INTRODUCTION

The purpose of this CRP is twofold: (1) to explore the feasibility of distributed simulation as a medium for conducting C^2 and situational awareness experiments and (2) to investigate the utility of the IDA SIMCTR as a venue for such experiments. To attain these objectives, a collection of simulated free-play, force-on-force armor engagements were conducted in the SIMCTR. In a very systematic manner, distinct command and control structures and situational awareness conditions were imposed on the combatants. Engagement outcomes were recorded and inferences were drawn about the impact of these C^2 structures and situational awareness conditions on the outcomes.

The intent was to attain the objectives by conducting sufficiently many moderately complex experiments (engagements or "runs") and demonstrating that the process yielded credible results.

Two teams of two players each opposed one another in each engagement. Each team commanded identical forces (14 M1A2s, one OH-58, and one Stinger-equipped M2). One team, the Red team, always operated under constant C^2 conditions. Their opponents, the Blue team, operated under conditions that varied from run to run. These will be described in a later slide.

The teams were constructed from a set group of four players. This allowed for three sets of opposing combinations to play one another throughout the experiment.

OBJECTIVE AND METHODOLOGY

- OBJECTIVE
  - To Demonstrate the Feasibility of Distributed Simulation as a Medium for Conducting C^2 and Situational Awareness Experiments
  - Explore the Utility of the IDA Simulation Center as a Venue for Such Experimentation

- METHODOLOGY
  - By Conducting a Series of Force-On-Force Distributed Simulations in Which the C^2 Structure and Situational Awareness Conditions of Opposing Sides Varies

Each of the two teams controlled two ModSAF workstations (with the standard two-dimensional graphical user interface; neither side had access to the Stealth viewer). The pair of workstations on a given team shared the control of one M1A2 company (14 tanks), one OH-58 observation helicopter,[1] and one M2 infantry-fighting vehicle equipped with Stinger missiles. Opposing forces were perfectly symmetric with respect to equipment.

The battlefield was a symmetric segment of digitized terrain constructed from a portion of the digital Hunter-Liggett terrain database. Specifically, the battlefield was constructed by mathematically reflecting a 10-kilometer (km) by 20-km swath of the Hunter-Liggett Military Reservation over one of its 20-km boundaries to form a symmetric 20-km by 20-km terrain patch.

The game objective was to destroy the opponent's Stinger-equipped M2. This "objective" was selected over others (such as a designated piece of terrain) after several test runs strongly suggested that it provided a good incentive for creative tactical thinking on the part of the test participants. A given run terminated when either side's M2 was destroyed or, if none were destroyed, after 40 minutes of simulation time (the runs took place in real time).

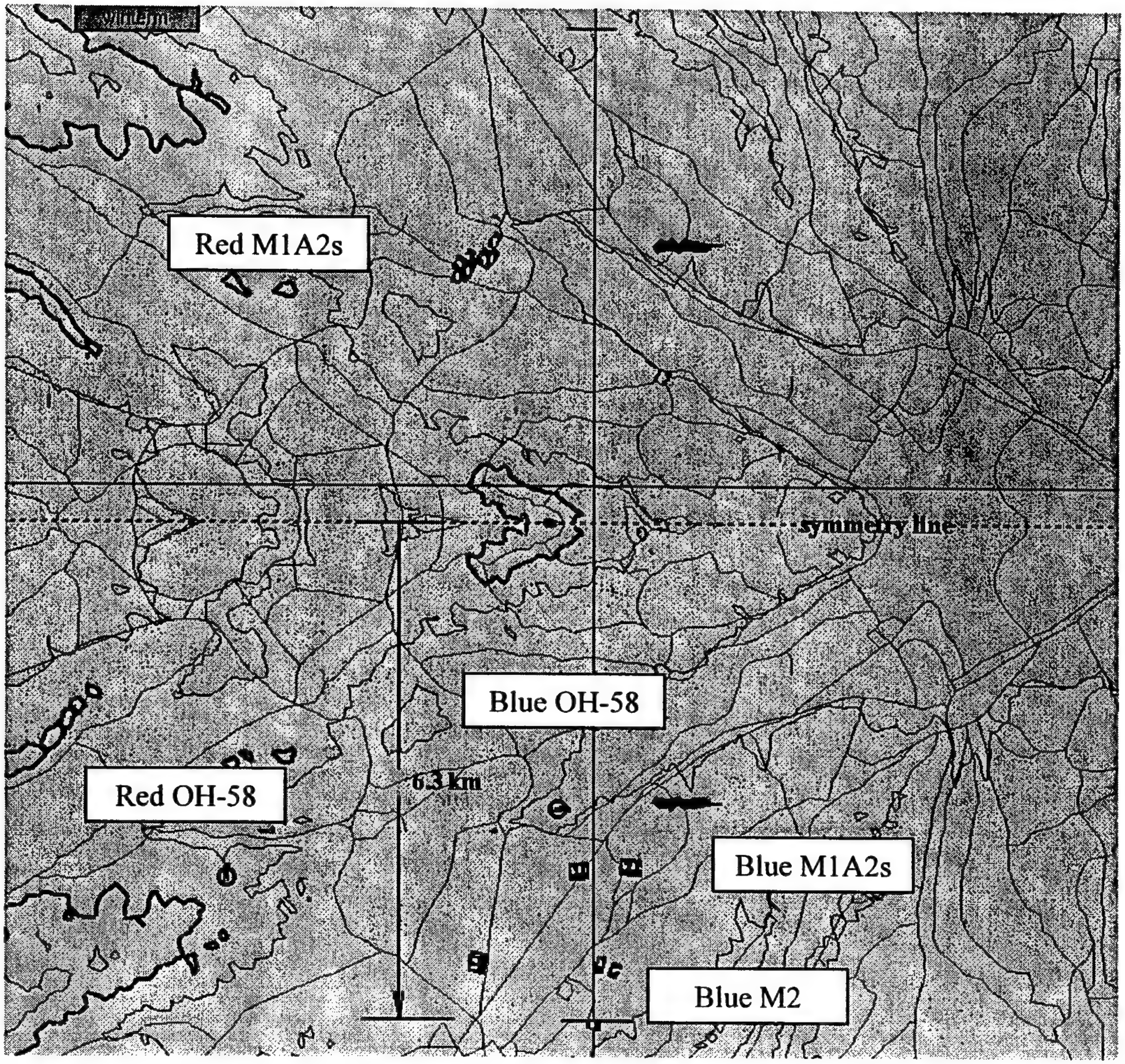
The two sides began each run from symmetrical points north or south of the line of symmetry. Thus neither side had any identifiable terrain advantage at the outset of the engagement.

1 The OH-58 helicopters were armed with Stinger missiles and Hydra 70mm rockets.

GAME STRUCTURE

- TWO OPPOSING 2-PERSON TEAMS, EACH OPERATING ModSAF SIMULATED
  - M1A2 Tank Company
  - OH-58
  - Stinger-Mounted M2
- SYMMETRIC TERRAIN
- OBJECTIVE WAS TO "CAPTURE THE FLAG"

This is an image of the terrain database with components of the Red (north) and Blue (south) forces in one of the actual trials. Starting positions for each force are denoted by short horizontal black lines at the top and bottom of the picture. Each starting point is approximately 6.3 km from the line of symmetry. In this trial, the Red observation helicopter is just to the west of the Blue M1A2 units. The Blue M2 is visible at the bottom, while the Blue OH-58 is just forward of the tank position. The Red M2 has been cropped from the image; otherwise, this picture is similar to what players would see under the high level of visibility or situational awareness.


Red M1A2s
Red OH-58
Blue OH-58
symmetry line
6.3 km
Blue M1A2s
Blue M2

The experiment was conducted as a 2^2 factorial design. The principal factors were situational awareness (visibility) and command structure. Each factor had a high and a low level:

- High visibility means that all vehicles on both sides are visible at all times to the Blue team operators
- Low visibility means that the Blue team could only see its own vehicles and Red vehicles detected by Blue vehicles
- High command structure means that the Blue operators took orders from an overarching Blue commander who had the same level of visibility as the Blue operators but conveyed his orders over a telephone from a remote location
- Low command means that the Blue operators make their own decisions.

The Red team always played at low visibility and without an overarching commander (i.e., Red played at both low levels).

PRINCIPAL FACTORS

- SITUATIONAL AWARENESS
  - High Level: Full View of the Battlefield
  - Low Level: View of Own Forces and Opponents Detected by Own Forces
- COMMAND AND CONTROL STRUCTURE
  - High Level: Commands Come From Higher Echelon ("Over-Commander")
  - Low Level: Operators Act on Their Own

Twenty-four runs were conducted during the course of the experiment. The "H" and "L" denote the high and low levels of each of the test conditions. For example, an "H" under the "Visibility" column indicates that the Blue team could see all entities on the battlefield, whereas an "L" in the same column implies that Blue could only see the items its own vehicles detected. Similarly, an "H" or "L" under "Command Level" indicates the presence or absence of a Blue "Over-Commander" in the given run.

The uppercase letters A, B, C, D, E, and F denote the various two-person operator teams.[2] Teams A, B, C, and D were made up from one group of four players. After run number 16, one of the four became ill and was replaced on team F (team E's members were from the original group). The letters X, Y, and Z denote the Blue "over-commanders" who participated in the experiment.

Note that six replicates of each test condition were conducted. Also, with the exception of trials 20 and 21, teams alternated sides (that is the Blue team became the Red team and vice versa) from run to run. This procedure was instituted to combat boredom among the players and was not due to any test design considerations. Each team remained intact for eight runs. In the first four runs in each group of eight, Red started from a position in the northern half of the symmetric terrain and Blue started in the southern half. Blue started in the north in the second set of four (while Red started in the south).

2 Players "1" and "2" made up team A and "3" and "4" were team B; players "1" and "3" were team C and "2" and "4" were team D; players "2" and "3' were team E, while team F was player "1" plus a substitute.

TRIAL MATRIX

Trial Order	Blue Visibility Level	Command Level	Blue Team	Over Commander
1	H	L	A	
2	L	H	B	X
3	H	H	A	X
4	L	L	B	
5	L	L	A	
6	H	H	B	X
7	L	H	A	X
8	H	L	B	
9	H	L	C	
10	H	H	D	Y
11	L	H	C	Y
12	L	L	D	
13	H	H	C	Y
14	L	H	D	Y
15	L	L	C	
16	H	L	D	
17	L	H	E	Z
18	L	L	F	
19	H	L	F	
20	H	H	E	Z
21	L	L	E	
22	H	H	F	Z
23	H	L	E	
24	L	H	F	Z

Two measures were to evaluate each trial: the ratio of Blue armor losses to Red armor losses; the engagement winner (the team destroying their opponent's M2). The first measure was selected, in part, because it is a traditional means of evaluating a military engagement. The armor exchange ratio includes both M1A2 and M2 losses from each side. While it may have been more standard to restrict the ratio to only one type of vehicle, the M1A2, for example, this would have presented a difficulty because some trials resulted in no tank losses. No distinction was made between catastrophic, mobility, or firepower casualties.

The second measure was the winner of the engagement. The objective in each trial was to find and destroy the opponent's Stinger-mounted M2. (Recall, each team had only one M2). The team that succeeded in this task was the winner. Trials in which neither side's M2 was lost were scored as ties. Trials were stopped immediately upon the first destruction, so that no trials resulted in two winners.

MEASURES

- LOSS EXCHANGE RATIO
  - Ratio of Blue Armor Losses to Red Armor Losses
- WINNER OF THE ENGANGEMENT
  - The Team That Captured the Other Team's "Flag" (Destroyed Their Opponent's Stinger-Mounted M2)

(This page is intentionally blank.)

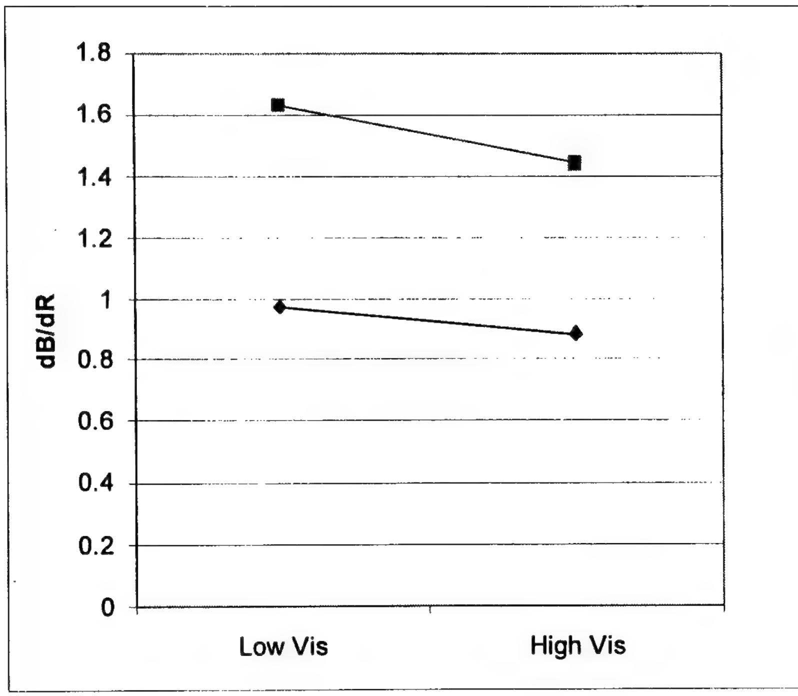
TEST RESULTS

The graph on the left shows the average exchange ratios for each of four treatment combinations of high and low Blue visibility and high and low command structure (presence or absence of an over-commander). The graph on the right shows the ratios of total Blue armor losses to total Red armor losses for each of the treatment combinations. The difference between the two graphs is that the first treats each run equally, but the second gives greater weight to trials in which more vehicles are destroyed. For example, Blue lost a large number of M1A2 tanks in three runs in which both principal factors were at the low level. In the remaining three, Blue lost relatively few vehicles. The runs in which Blue lost more armor had greater influence and resulted in a higher recorded value on the right than the corresponding point on the left.

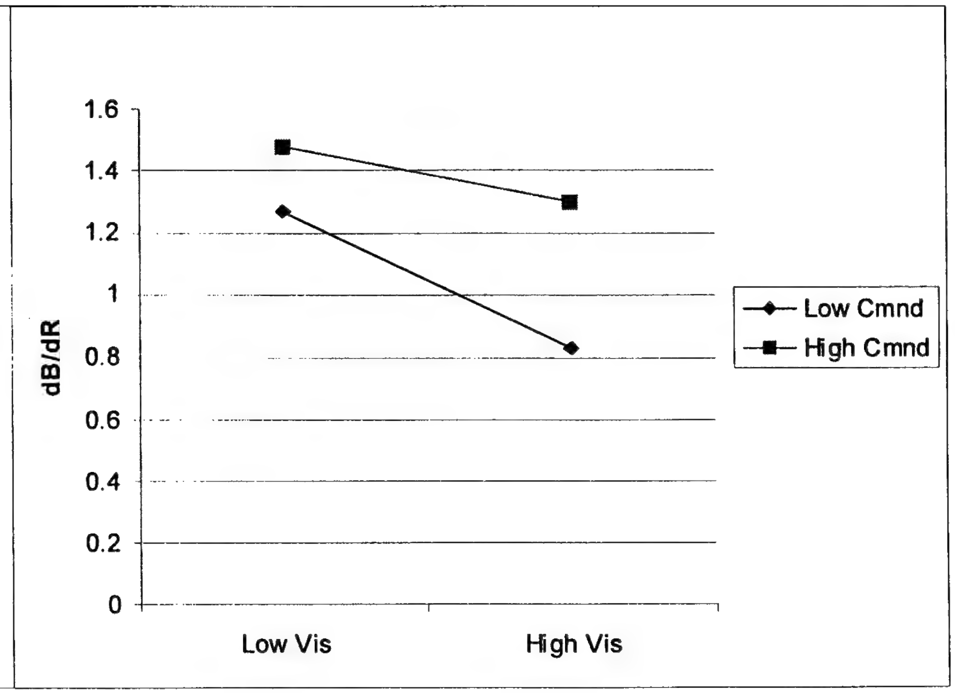
Both graphs indicate that the presence of an over-commander increases Blue's losses relative to Red's. Both also indicate that giving Blue the high level of visibility, that is a full view of the battlefield, benefits Blue (as expected). In terms of the left-most graph, however, this benefit doesn't appear to offset the impact of the more complex command and control structure.

Finally, the graph on the right suggests that Red fares better than Blue when both play under identical conditions. One should be cautioned against drawing that conclusion, however, because (1) only six trials were conducted where both factors were low; (2) when trials are given equal weight, the exchange ratio under these conditions is nearly unity (see the left graph).

LOSS EXCHANGE RATIO
(Blue/Red Armor Losses)



Average Exchange Ratio



"Composite" Exchange Ratio
(ratio of losses for each category)

In terms of the number of games won, Blue appears to benefit from the low-level command structure. Blue won seven games under this condition and only three under the high level. Situational awareness/visibility appears to affect Blue also, but perhaps not as dramatically: Blue won four games under low-visibility conditions and six under high conditions. The situation for Red is more symmetrical with respect to the principal factors. Red won four games when Blue had an over-commander or low visibility and two under the opposite conditions.

Ties were evenly divided with respect to visibility but occurred more frequently when Blue had an over-commander. Since the cell sizes are small, Fisher-Irwin Exact tests (as opposed to Chi-square tests) were applied to the data in the accompanying boxes. Unsurprisingly, no interdependence was found between visibility and command structure with respect to wins, ties, and losses. This issue will be revisited in a later slide where logistic regression is used to determine the significance of the principal factors and their interaction.

WINS AND TIES BY TEST CONDITION

Blue Wins

CMND	Visibility Low	Visibility High
Low	3	4
High	1	2

Red Wins

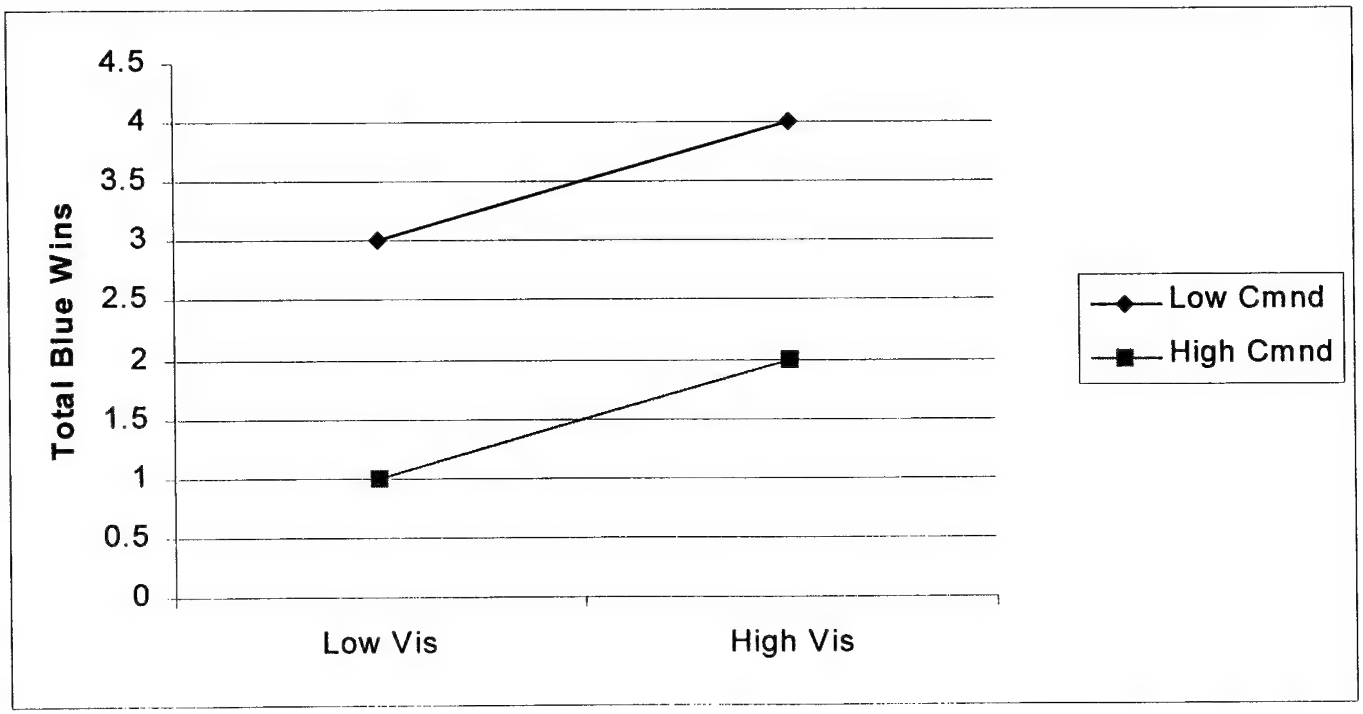
CMND	Visibility Low	Visibility High
Low	1	1
High	3	1

Ties

CMND	Visibility Low	Visibility High
Low	2	1
High	2	3

Little or no interaction or synergy existed between the two principal factors: situational awareness (visibility) and command structure. That is, the impact of the over-commander did not depend on visibility level. Independent of whether the latter was high or low, the presence of the over-commander resulted in two fewer wins for Blue.

NUMBER OF GAMES WON BY BLUE
(By Command And Visibility Condition)



(This page is intentionally blank.)

ANALYSIS

For purposes of analysis, tests were rearranged into a set of six groups (shaded area), each corresponding to a complete replication of the experiment with a given team playing Blue and a given team playing Red.

Within each group or replication, the trials are further separated into two blocks according to date of the trial and force starting positions with respect to the line of symmetry. Trials in a given block took place on the same day (or, in the sole case of replication 5, successive days). Blocks within a replication took place at least 2 days apart and, in some cases, as much as 1 week apart. Even numbered blocks began with Blue in the north and Red in the south (and vice versa for odd numbered blocks).

This is an example of a partially confounded 2^2 factorial experimental design. Roughly speaking, replication 1 confounds "Visibility" because team A has high visibility in block 1 and low visibility in block 2. Similarly, "Command" is confounded in replicate 5 because team E has high command in block 9 and low in block 10. The interaction between "Visibility" and "Command" is confounded in replication 3 for slightly more abstract reasons. Interaction is measured by first combining outcomes at both high levels and both low levels, then comparing this result with the combined outcomes of the mixed levels. In replicate 3, this corresponds to the difference between blocks 5 and 6.

This design is more sensitive than the simpler complete block design in which one computes the sum or squares due to replications, but not the sum of squares due to blocks within replications.

2^2 FACTORIAL WITH PARTIAL CONFOUNDING

Trials	Blue's Surviving Elements: Helicopters	Blue's Surviving Elements: M1A2	Blue's Surviving Elements: Air Defense	Red's Surviving Elements: Helicopters	Red's Surviving Elements: M1A2	Red's Surviving Elements: Air Defense	Win	Game Conditions: Blue Visibility	Game Conditions: CMND	Game Conditions: Blue Team	dB/dR	
Replication 1												
1	0	7	1	0	0	0	b	H	L	A	0.467	block 1
3	0	1	1	0	4	1	(tie)	H	H	A	1.300	
5	0	0	1	1	4	1	(tie)	L	L	A	1.400	block 2
7	0	4	1	0	6	1	(tie)	L	H	A	1.250	
Replication 2												
2	1	5	0	1	9	1	r	L	H	B	2.000	block 3
4	0	4	1	0	3	0	b	L	L	B	0.833	
6	0	13	0	0	8	1	r	H	H	B	0.333	block 4
8	1	9	1	0	5	0	b	H	L	B	0.500	
Replication 3												
9	1	9	1	0	8	0	b	H	L	C	0.714	block 5
11	0	4	0	0	3	1	r	L	H	C	1.000	
13	0	3	1	0	12	0	b	H	H	C	3.667	block 6
15	0	14	1	0	14	0	b	L	L	C	0.000	
Replication 4												
10	1	13	1	0	10	0	b	H	H	D	0.200	block 7
12	1	14	1	1	14	0	b	L	L	D	0.000	
14	1	0	0	0	9	1	r	L	H	D	3.000	block 8
16	0	2	0	0	6	1	r	H	L	D	1.625	
Replication 5												
17	0	5	1	0	7	1	(tie)	L	H	E	1.286	block 9
20	0	1	1	0	6	1	(tie)	H	H	E	1.625	
21	1	14	0	0	13	1	r	L	L	E	1.000	block 10
23	1	8	1	0	8	0	b	H	L	E	0.667	
Replication 6												
18	0	1	1	0	9	1	(tie)	L	L	F	2.600	block 11
19	0	2	1	0	5	1	(tie)	H	L	F	1.333	
22	0	2	1	0	6	1	(tie)	H	H	F	1.500	block 12
24	1	4	1	0	7	0	b	L	H	F	1.250	

The ANOVA for the partially confounded 2^2 factorial design indicates that command (C^2 structure) is significant at the 10 percent level. Neither visibility, the other principal factor, nor the interaction between command and visibility are significant.

This ANOVA supports analytically what is depicted in the graphs on page 15. There it was shown that the presence of an over-commander was associated with an (unfavorable for Blue) increase in the exchange ratio. The ANOVA indicates that the impact of command structure on the observed variability is significant.

ANALYSIS OF VARIANCE OF PARTIALLY CONFOUNDED FACTORIAL DESIGN (With Respect to Blue/ Red Armor Losses)

ANOVA	SS	df	MS	F
Replicates	1.3180683	5	0.2636	0.3841
Blocks within replicates	7.7801566	6	1.2967	1.8892
Visibility (from reps 3,4,5, & 6)	0.0892871	1	0.0893	0.1301
Command (from reps 1,2,3, & 4)	3.24965	1	3.2497	4.7344 *
Interaction (from reps 1,2,5,& 6)	0.2114357	1	0.2114	0.308
Error	6.17748	9	0.6864	
Total	18.826078	23		

* Significant at the 10% Level

For purposes of analysis, ties and Red victories were grouped together. Outcomes of the games, therefore, were dichotomous and were scored as Blue wins or losses (non-wins). Dichotomous data are not amenable to linear models with their underlying normality assumptions but are instead more reasonably addressed through logit or probit regression. These models maximize a likelihood function that is based, in the dichotomous case, on the binomial distribution.

The accompanying slide shows SPSS stepwise logistic regression output generated from Blue's win/loss record. The initial step included all categorical variables of interest such as C^2 level (commander), visibility (situational awareness), their interaction, and a constant term. Variables were removed or entered depending on the significance of their contribution to a certain likelihood ratio.

After three iterations, only constant term and the variable corresponding to command level (C^2 structure) were retained by the regression algorithm. The Wald test, which compares the estimated coefficient corresponding to the variable of interest to its standard error, indicates that command level is significant at about the 10-percent level. Another measure of significance, a Chi-squared statistic applied to the likelihood ratio, indicates that command is significant at the 9.4-percent level.

STEPWISE LOGISTIC REGRESSION ON WINS VS. LOSSES OR TIES

Step 1

Parameter	Estimate	S.E.	Wald†	p-value
• CONSTANT	0.0	0.817	0.0	1.0
• VISIBILITY	0.693	1.190	0.339	0.560
• CMND	-1.609	1.367	1.388	0.239
• INTERACTION	0.223	1.835	0.015	0.903

Step 3 (final)

Parameter	Estimate	S.E.	Wald	p-value
• CONSTANT	0.337	0.586	0.330	0.566
• CMND	-1.435	0.887	2.616	0.106 *

Log Likelihood (LL) = -14.898
Log Likelihood of constants only model = LL(0) = -16.301
2*[LL - LL(0)] = 2.805 with 1 df Chi-square p-value = 0.094 *

* Impact of an command structure approaches significance with respect to wins Vs. losses or ties.

† Wald statistic = $(\text{Estimate}/\text{S.E})^2$ has Chi-square distribution

(This page is intentionally blank.)

COMMENTS AND CONCLUSIONS

The high-level command and control structure differed from the low level because of the presence of a Blue "over-commander." This individual directed Blue maneuvers down to the platoon level and occasionally to the vehicle level. The over-commander was not co-located with the ModSAF operators but was remotely positioned in a separate room and communicated to the Blue operators over a speaker phone. The over-commander had access to a separate workstation with a battlefield image identical to that of the Blue operators.

Blue appeared to suffer in the presence of an over-commander for two distinct reasons. The over-commander could not process the information appearing on his GUI as fast as the operators. They were responsible for half the force and could assess the dangers and opportunities appearing before them more rapidly. On occasion, an operator would have to ask repeatedly for permission to perform one maneuver or another during periods of high activity while the over-commander was in the process of assessing the entire battlefield situation.

Communications between the over-commander and the operators was a problem. Sometimes the over-commander's orders were not clear to the operators. Terminology was a problem. Delays experienced while requesting clarification may have contributed to lost opportunities and increased Blue's vulnerability.

Situational awareness, or the "visibility" level referred to throughout the annotated briefing, had little effect in these exercises. This may have been due to many factors, including some which are artifacts of ModSAF. Specifically, vehicles that were destroyed during the course of the engagement continued to "report" enemy detections. Although this did not make detections cumulative (in the sense that they never decreased), it may have had the effect of enhancing the number of detections over time. This may have mitigated the difference between the high- and low-visibility levels.

Another factor was the limited battle-space in which the engagements took place. Although it was possible to hide one's own M2 from an opponent with limited visibility, it was nearly impossible to hide the bulk of the armor force. The observation helicopter could traverse the battlefield in relatively short order and find most of the armor platoons (if it could avoid being shot down). Since this process would make the detected units visible to an opponent, it is not unreasonable that visibility level had a muted effect with respect to armor exchange ratios. It is less clear why visibility wasn't an important factor with respect to Blue wins and losses.

"CONCLUSIONS"

- THE PRESENCE OF AN "OVER-COMMANDER" REDUCED BLUE'S LIKELIHOOD OF WINNING.
- THE PRESENCE OF AN "OVER-COMMANDER" HAD A SIGNIFICANT AND UNFAVORABLE (TO BLUE) IMPACT WITH RESPECT TO ARMOR EXCHANGE RATIOS.
- SITUATIONAL AWARENESS ("VISIBILITY") WAS NOT A SIGNIFICANT FACTOR WITH RESPECT TO EITHER MEASURE (VICTORIES OR EXCHANGE RATIOS)

The results of this Central Research Project with respect to command and control structure are in concert with those of the July 1997 Joint Theater Missile Defense Attack Operations (JTMD-AO) exercise. As reported in the Joint Task Force's Phase II/III Test Report, May 1998, the JTMD-AO exercise demonstrated the enhanced ability to conduct attack operations in a "streamlined" C^2 environment. The exercise entailed a series of simulation runs in which two levels of command and control were implemented. In the more complex level, a Joint Air Operations Center (JAOC) received reports from sensor platforms and directed attack assets (fighter aircraft) against nominated targets. Some of the sensor platforms were JSTARS aircraft.

In the less complex (or "streamlined") C^2 structure, the decision making authority was placed on the JSTARS. This obviated the need for sensor reports to go through a ground commander and may have reduced the "cycle time" for prosecuting targets. In any case, attack operations were more successful under the "streamlined" structure.

Although the JTMD-AO exercise was much more complex and far reaching than this CRP, there were some similarities between the two. Specifically, the JAOC is analogous to the over-commander and the Blue ModSAF operators are analogous to the JSTARS. In both cases, the less complex C^2 structure (or a localized decision process) appeared to be an enhancement.

Finally, there may be a trend toward local decision making in all branches of the U.S. military. Recent literature supporting this trend can be found in a recent Army Times article by G. Seffers (*Army Times*, 8/10/98).

COMMENTS REGARDING C^2 STRUCTURE

- LOCALIZED DECISION PROCESS
  - May Be Current Trend in U.S. Military

- CRP RESULTS ARE IN CONCERT WITH JTMD-ATTACK OPERATIONS EXERCISE
  - "Streamlined" C^2 Cycle

The purpose of this CRP was to demonstrate the feasibility of distributed simulation as a medium for conducting C^2 experiments and to investigate the utility of the IDA Simulation Center as a testbed for such experiments. To accomplish the first point, two factors were investigated: situational awareness and command and control structure. Distributed simulation as manifested by ModSAF was difficult to implement. The two visibility levels attainable in ModSAF were not sufficiently different from one another to make a significant difference in outcomes. This was unanticipated and is arguably an unrealistic aspect of ModSAF. Also, certain obvious enhancements to detection algorithms might rectify the situation. For example, terminating a destroyed vehicle's ability to detect opponents would be one such enhancement.

Modeling different levels of C^2 proved easier than anticipated. The one implemented simply entailed a remote commander who communicated with his operators by phone. Other schemes are possible—communicating by e-mail, for example—without incurring additional software or equipment. Additional levels of command could be added in a more elaborate exercise.

The simulation center itself was very conducive to this exercise. The Blue and Reds teams had separate rooms (shared with other analysts), and the over-commander had a separate area from which he could conduct operations. The "cell" constructed for these experiments remained intact throughout the duration of the tests and could be reconstructed for future experiments.

COMMENTS REGARDING DISTRIBUTED SIMULATION AS A MEDIUM FOR C^2 EXPERIMENTS

- SITUATIONAL AWARENESS
  - More Difficult to Model Than Anticipated
  - Intended Effect Probably Not Achieved
- C^2 STRUCTURE
  - More Easily Implemented Than Anticipated
- SIMCENTER AS A TEST FACILITY
  - " C^2 Cell" Established for Duration of Tests
  - Facility Conducive to More Elaborate Testing

(This page is intentionally blank.)

Appendix A

GLOSSARY

GLOSSARY

ANOVA	Analysis of Variance
CRP	Central Research Project
GUI	Graphical User Interface
JAOC	Joint Air Operations Center
JSTARS	Joint Surveillance and Target Acquisition Radar System
JTMD-AO	Joint Theater Missile Defense Attack Operations
ModSAF	Modular Semi-Automated Forces
SGI	Silicon Graphics
SIMCTR	Simulation Center
SPSS®	Statistical Package for Social Sciences

(This page is intentionally blank.)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1998	Final

4. TITLE AND SUBTITLE
Distributed Simulation-Based C^2 Experiments

5. FUNDING NUMBERS
DASW-01-94-C-0054
CRP 9001-151

6. AUTHOR(S)
Dennis F. DeRiggi, Richard W. Carpenter, Windsor W. Lin, Timothy M. Stone, Victor K. Wong

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, Va 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Document D-2194

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
FFRDC Programs
2001 N. Beauregard Street
Alexandria, VA 22311-1772

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Command and control and situational awareness are critical issues in the modern battlefield. This report summarizes the results of a 2^2 factorial experiment in which the command and control and situational awareness were the principal factors. Two command and control structures were imposed on players who controlled simulated armor forces in this experiment: one in which a high-level commander made all tactical decisions and another in which lower-level (company level and below) made decisions. Similarly, two levels of situational awareness were imposed. At one level, all forces on the battlefield were visible; at the second level, only one's own forces were visible. An analysis of variance and logistic regression indicated that placing decision-making authority in a higher-level commander adversely affected loss exchange ratios and lessened the odds of winning an engagement.

14. SUBJECT TERMS
Command and Control, Situational Awareness, Distributed Simulation, Factorial Design, Partial Confounding, Logistic Regression, Analysis of Variance

15. NUMBER OF PAGES
51

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMIT OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Unlimited